ORGANIC LIGHT-EMITTING DIODES

LIGHTING TOWARD A SUSTAINABLE ENVIRONMENT

Colleen Cleary (Undergraduate)

Leo Panish (HS Student)

Angelo Angeles (HS Teacher)

Dr. Reginald Eze (Mentor)

Dr. Yasser Hassebo (Mentor)

Objective

Changing the parameters of a simulated OLED and analyzing the effects of these changes on OLED emission patterns.

The results of this study provide a template for a potential OLED with enhanced color-brilliance and brightness.

ORGANIC LIGHT EMITTING DIODE LIGHTING

- Introduction
  - What is an Organic Light-Emitting Diode?
  - OLEDs Compared to Other Light Sources
  - History and Applications of Organic Light-Emitting Diodes
  - How Does it Work?
- Method
- Results and Conclusion
- Why is it the Next Generation of Technology?

What is an OLED?

Organic

A compound that is carbon-based.

Light-Emitting Diode (LED)

An electronic device that emits light when an electrical current is applied to it.

What is an OLED?

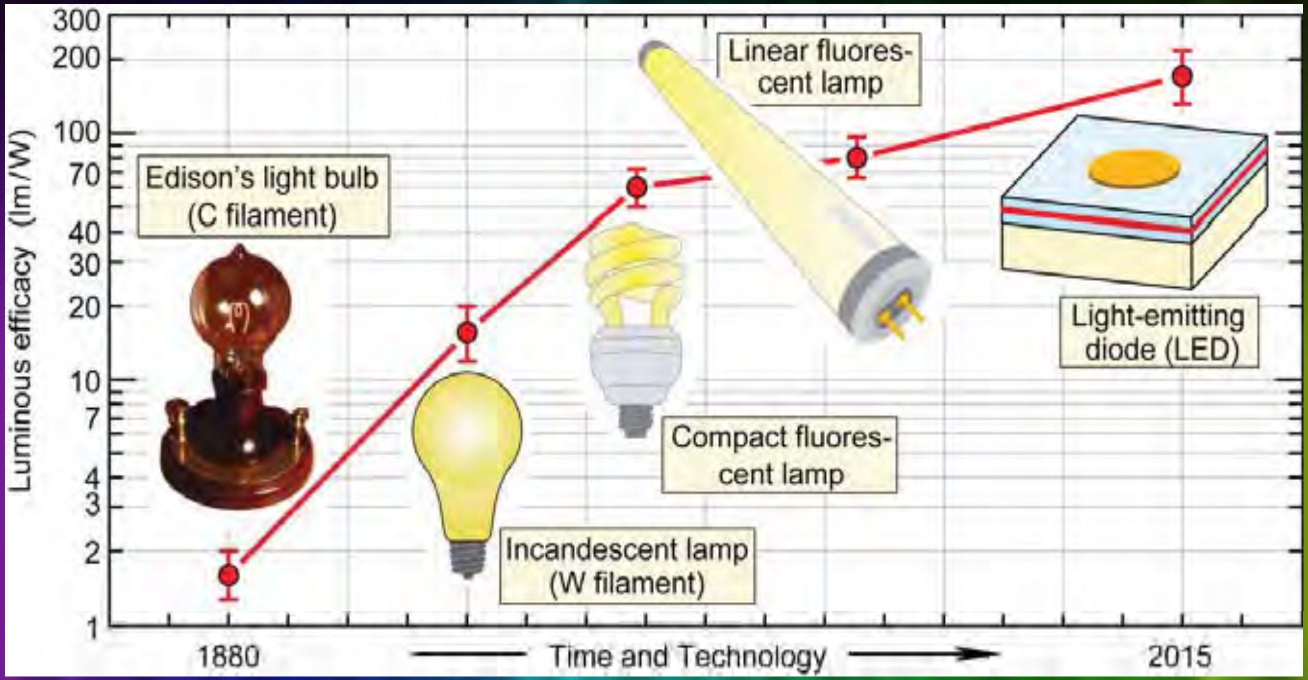
http://www.osadirect.com/static/img/news/img20130708lgchem01.jpg

An area light source that contains layers of thin, flexible sheets of organic electroluminescent material.

What is an OLED?

http://assets.inhabitat.com/wp-content/blogs.dir/1/files/2011/09/UD-OLED2.jpg

Evolution of Light

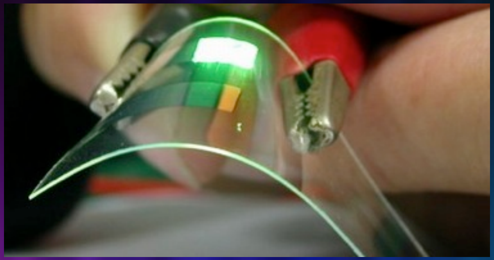


www.lightemittingdiodes.com

	Efficiency	Lifetime
Incandescent lamp	17.5 lm/W	0.9 years
Compact fluorescent lamp	49-75 lm/W	7.3 years
Linear fluorescent lamp	67-110 lm/W	5.0 years
Light-Emitting Diode	up to 140 lm/W	13.7 years
Organic Light-Emitting Diode	120 lm/W	36.5 years

Lifespan found from GE 60W bulbs calculated for 3 hrs/day

OLEDs vs. LEDs



https://upload.wikimedia.org/wikipedia/commons/f/f2/OLED_EarlyProduct.JPG

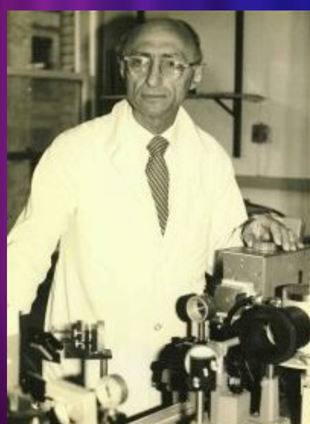
http://www.noguge.com/thumbnail/l/led-lights-8.jpeg

- **OLED**s are area sources
- Small enough to be used as pixels in a display
- Modern displays can be less than 1mm thick and weigh less than 4.5 lbs
- Can be made flexible

- **LED**s are point sources
- Used to backlight LCD TVs
- Modern displays can be less than 1.5 inches thick and weigh less than 35 lbs
- Encased in epoxy (plastic capsule)

History of OLEDs

- 1950's: André Bernanose observed electroluminescence in organic materials.
- 1960: Martin Pope developed a technique to connect an electric current to organic crystals.



https://upload.wikimedia.org/wikipedia/commons/a/aa/Martin_Pope.jpg

http://blog.virginiatoy.com/wp-content/uploads/2013/09/EDC-Glowsticks.jpg

http://i2.wp.com/www.stevehuffphoto.com/wp-content/uploads/2012/01/kodak-logo.jpg

- 1987: Ching W. Tang and Steven Van Slyke at Eastman Kodak reported the first small-molecule OLED device.

Commercialization of OLEDs

- In 2003, Kodak began integrating OLED technology with their digital cameras.

http://cdn.itechnews.net/wp-content/uploads/2009/01/sony-bravia-xel-1-ultra-slim-oled-tv.jpg

http://http://img.tomshardware.com/de/2003/08/08/fotokuenstler_bis_5_megapixel_16_digitalkameras_im_fokus/kodak_d01.jpg

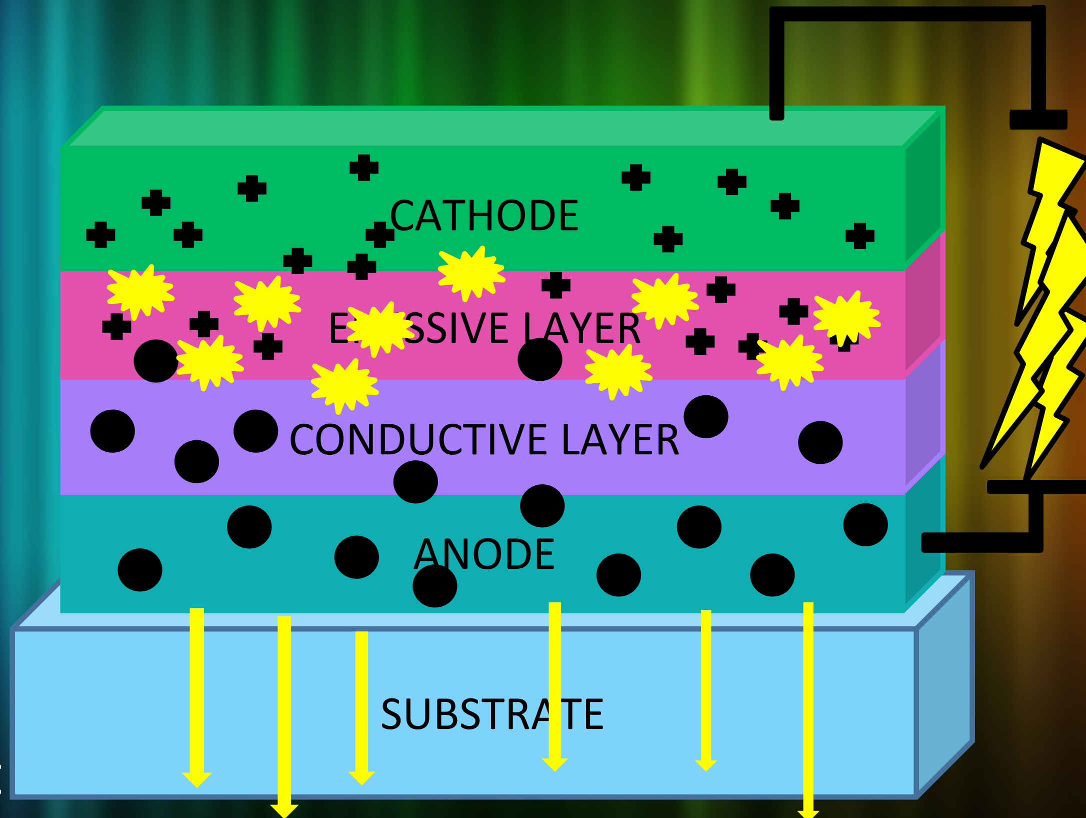
http://http://www.techbel3arabi.com/wp-content/uploads/2015/05/lg-wallpaper-tv.jpg

- In 2007, Sony announced the XEL-1, the first OLED TV.

- In 2015, LG unveiled the world's thinnest OLED TV.

How does an OLED work?

- Potential difference is applied to the two electrodes.
- Electrons travel from cathode to anode.
- Holes recombine with the electrons in the emissive layer.
- Energy is released as light and directed towards the substrate.

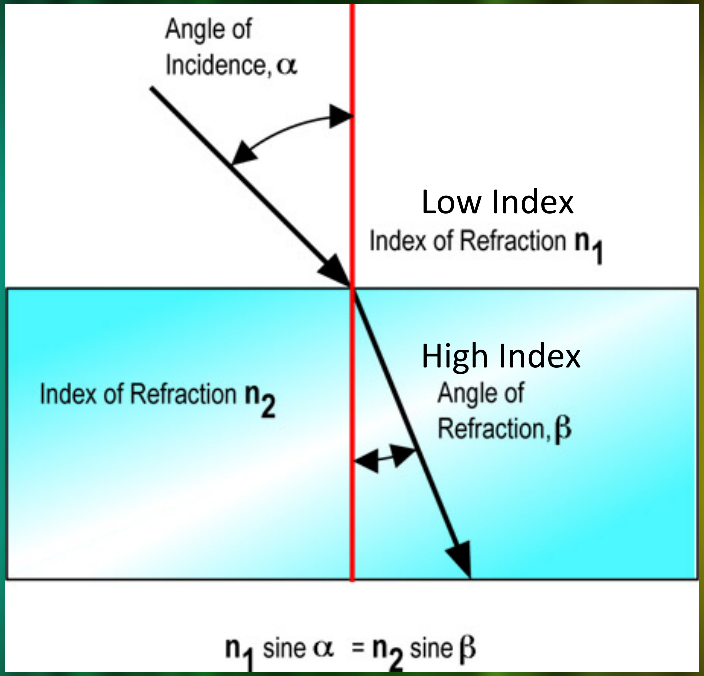


ORGANIC LIGHT EMITTING DIODE LIGHTING

- Introduction
  - What is an Organic Light-Emitting Diode?
  - OLEDs Compared to Other Light Sources
  - History and Applications of Organic Light-Emitting Diodes
  - How Does it Work?
- Method
- Results and Conclusion
- Why is it the Next Generation of Technology?

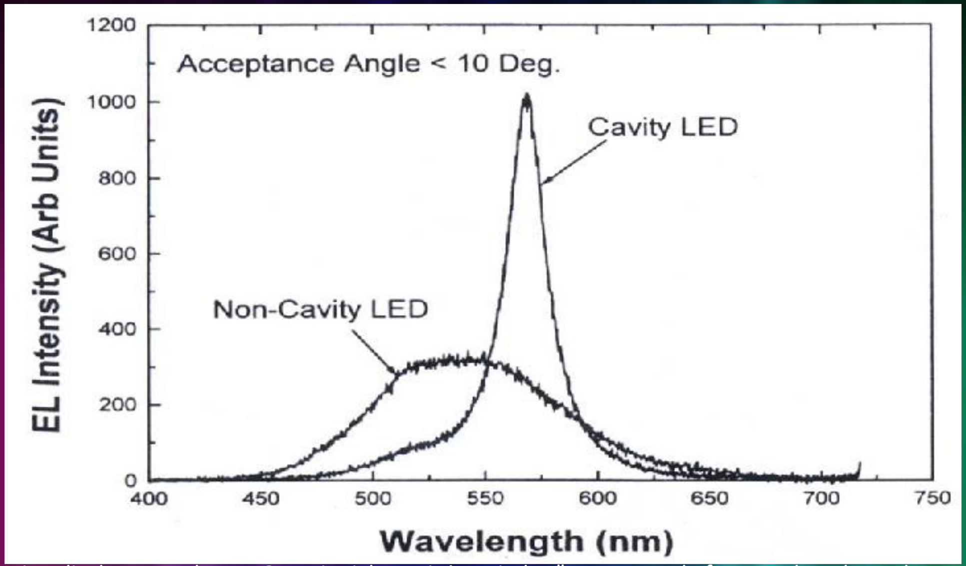
Refractive Index

- Property of materials
- Defined as $n=c/v$
- Used to determine values such as incident angle of the m^{th} layer



https://d2jmvrsizmvf4x.cloudfront.net/if5aenByR5yU8Nm5WsXF_refraction.jpg

Adding Microcavities and DBRs



"Microdisplays Based upon Organic Light-emitting Diodes." IBM Journal of Research and Development

https://upload.wikimedia.org/wikipedia/commons/3/30/Partial_transmittance.gif

Low Index High Index

Microcavity

Creates standing waves that amplify the light

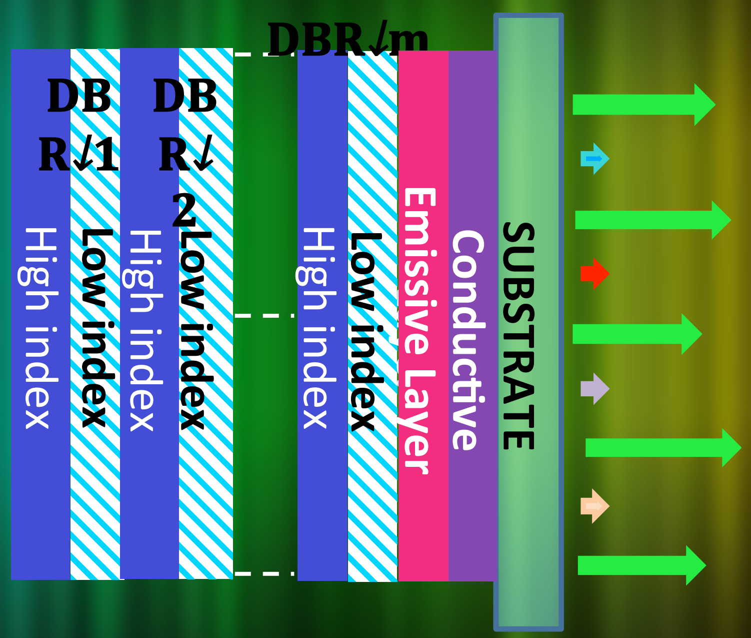
DBR

Produces standing waves using phase change

Nine-Step Algorithm

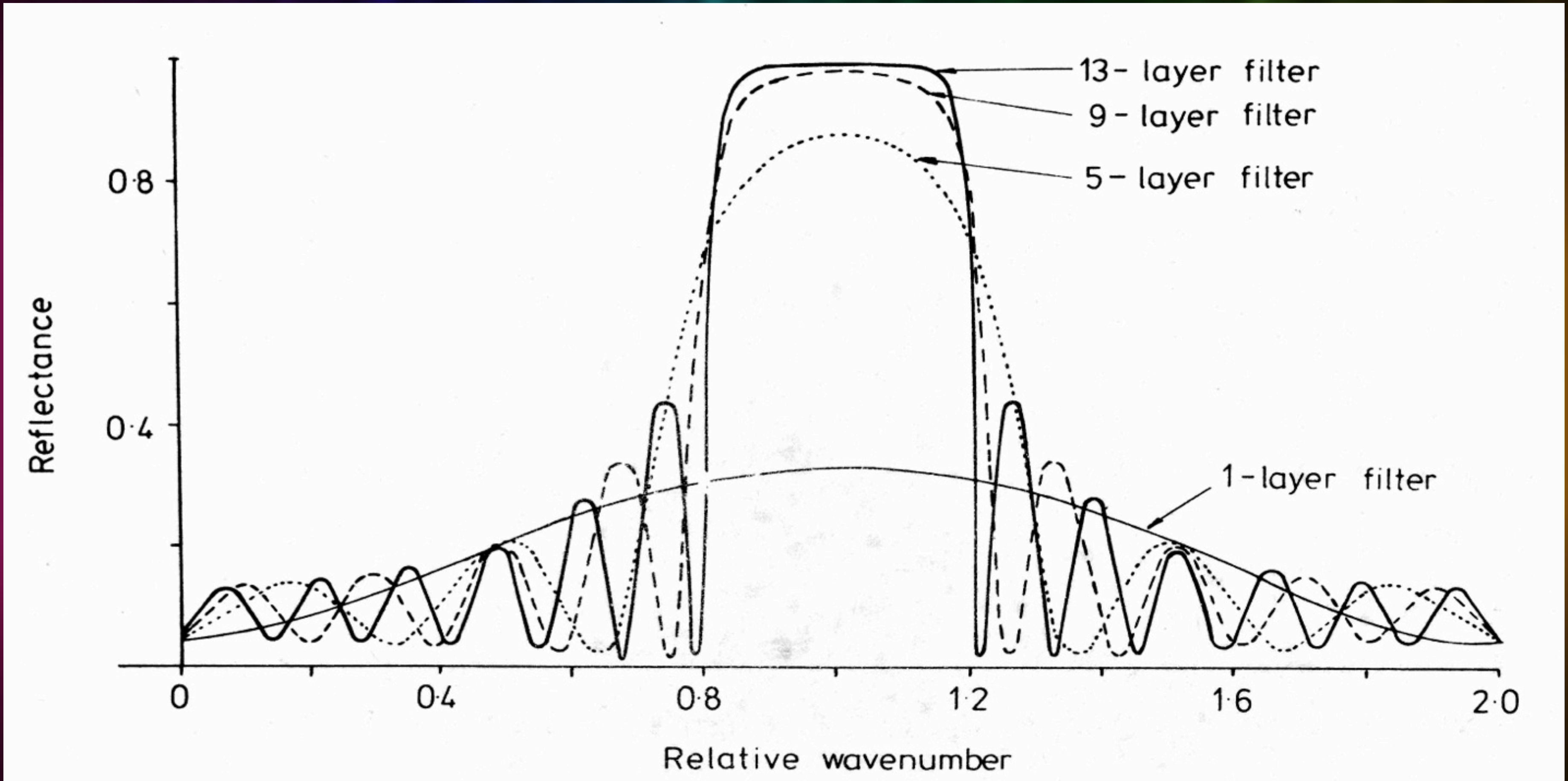
1. User input values
2. Converting values for calculation
3. Outer loop for Incident angles (-90 degrees < q < 90 degrees)
4. Calculating Refracted angles and Layers thickness
5. Calculating the Optical admittance
6. Inner loop for Wavelength (Bragg wavelength +/- 180)
7. Calculating Phase factor and Characteristic Matrix
8. Computing the Transmittivity and Reflectivity values
9. Graphs

First Simulation



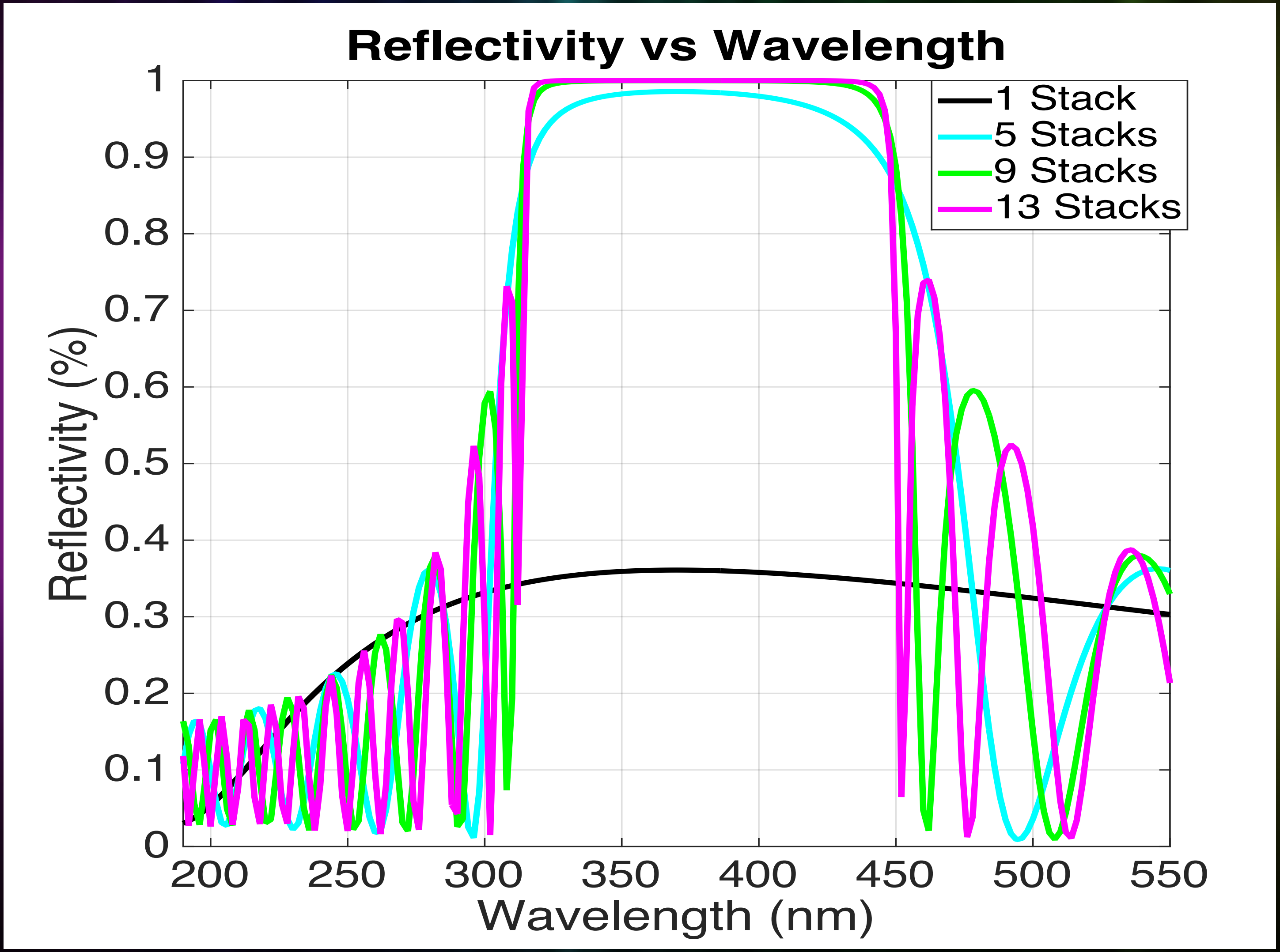
OLED with DBRs

Validity of Code



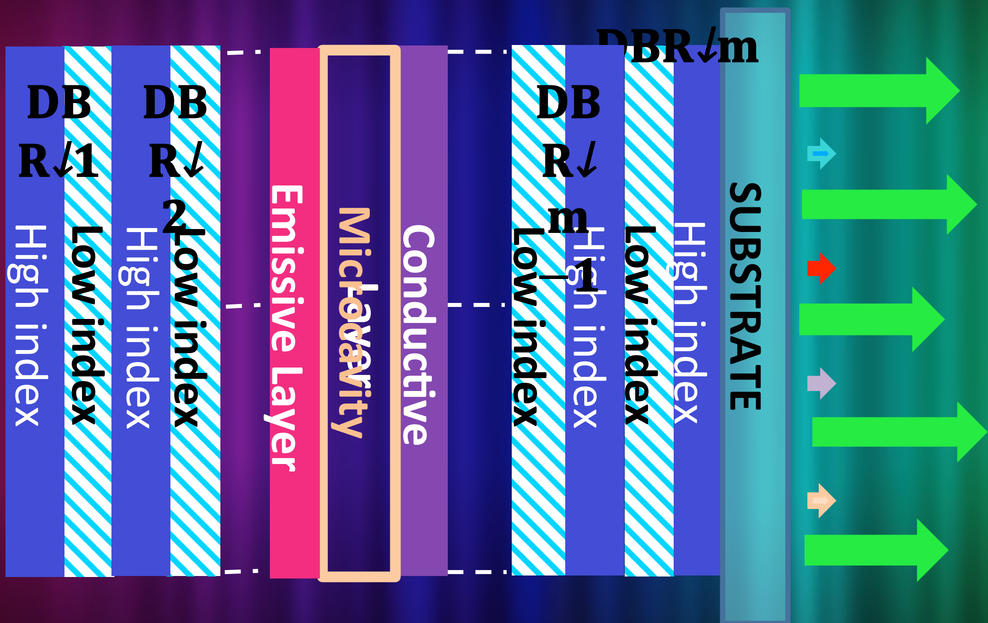
Liddell, Heather Mary., and H. G. Jerrard. "Periodic Multilayers and the Classical Stack." Computer-aided Techniques for the Design of Multilayer Filters. Bristol: A. Hilger, 1981. 14-18. Print.

Validity of Code

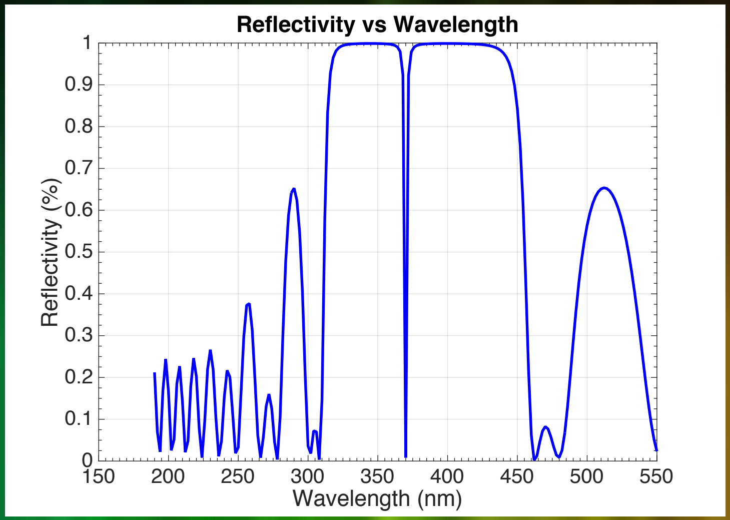


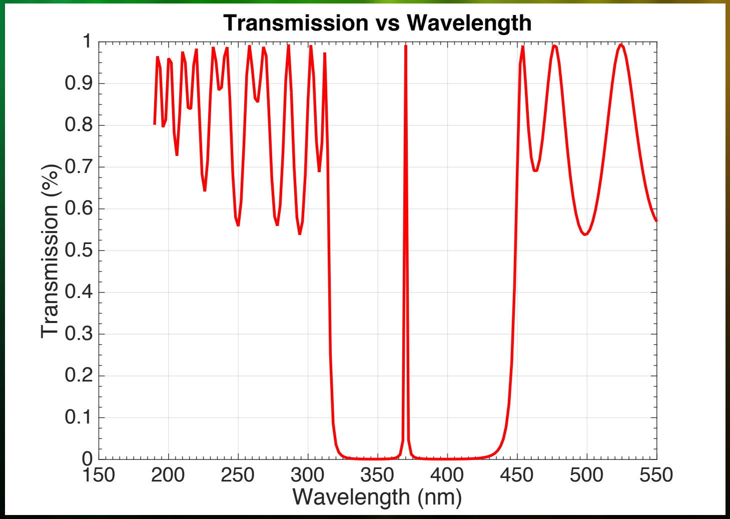
Approach

Final Simulation



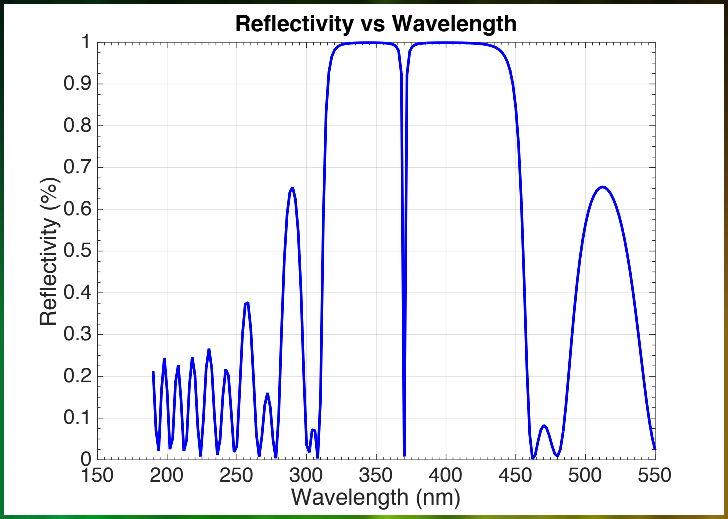
OLED with DBRs and a microcavity

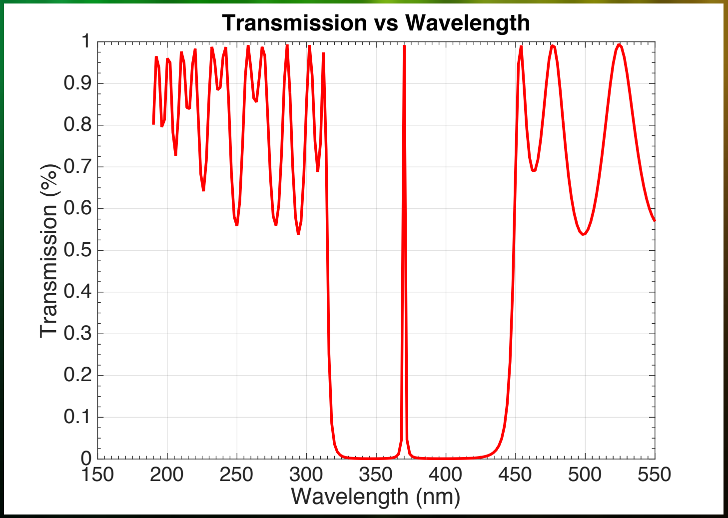




Approach

- Goals:
  1. Maximum transmission at Bragg wavelength
  2. Maximum reflection at surrounding wavelengths
- Focus on small bandwidth
- Parametric study
- $R+T=1$





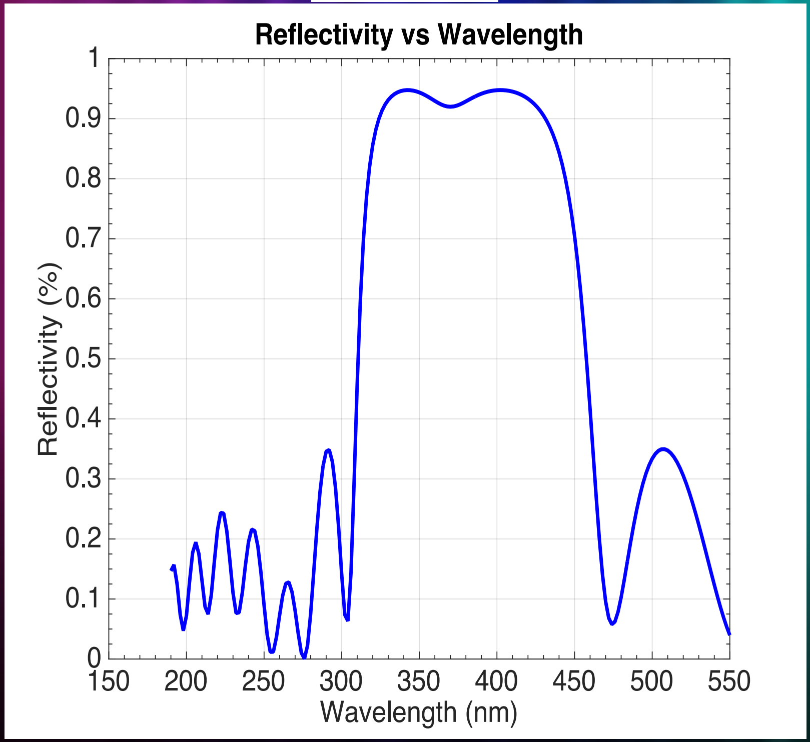
ORGANIC LIGHT EMITTING DIODE LIGHTING

- Introduction
  - What is an Organic Light-Emitting Diode?
  - OLEDs Compared to Other Light Sources
  - History and Applications of Organic Light-Emitting Diodes
  - How Does it Work?
- Method
- Results and Conclusion
- Why is it the Next Generation of Technology?

Results

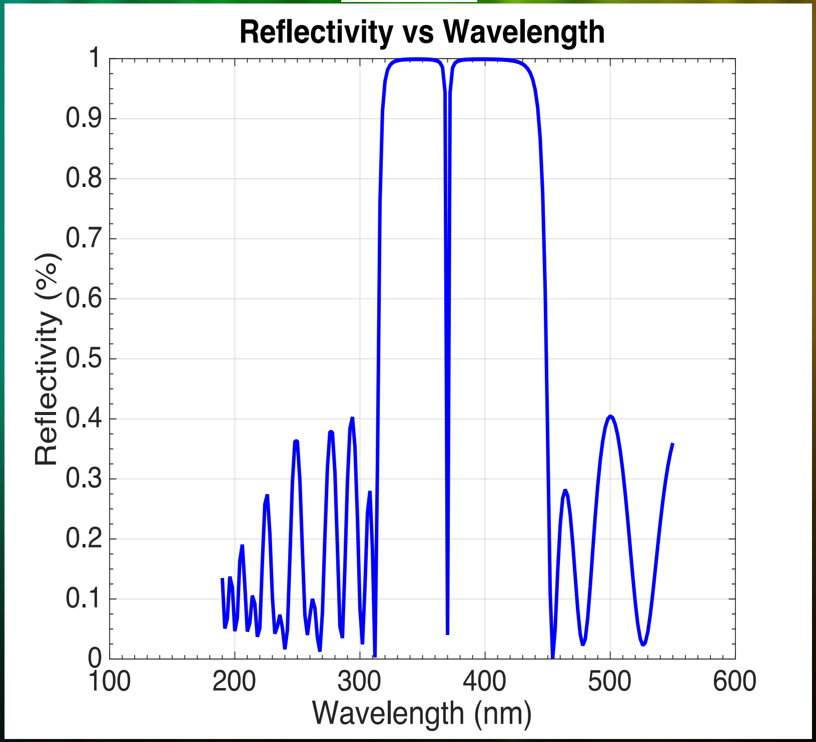
Changing the number of DBR stacks above and below the cavity affects transmission.

Before



Unequal Stacks

After

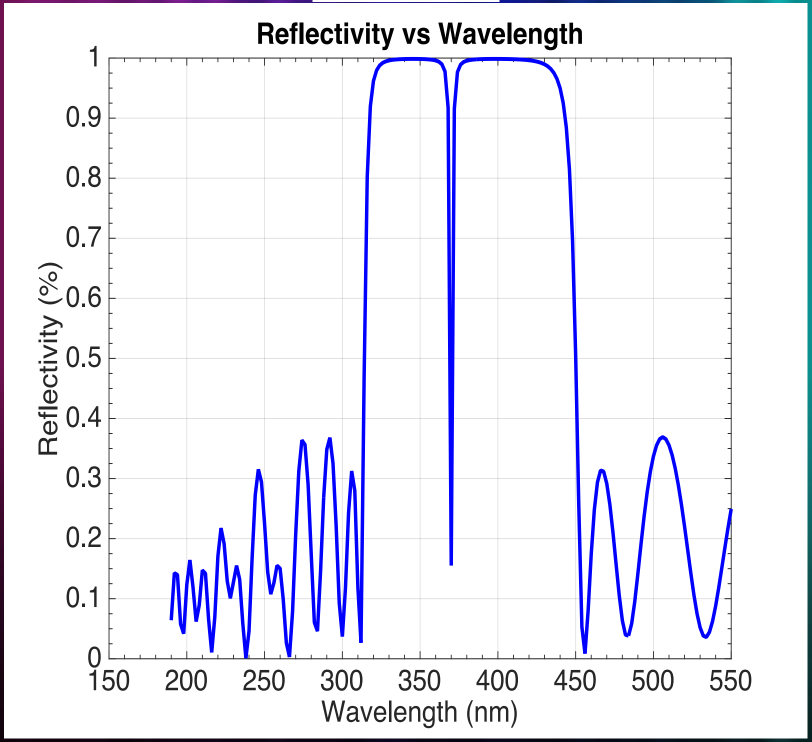


Equal Stacks

Results

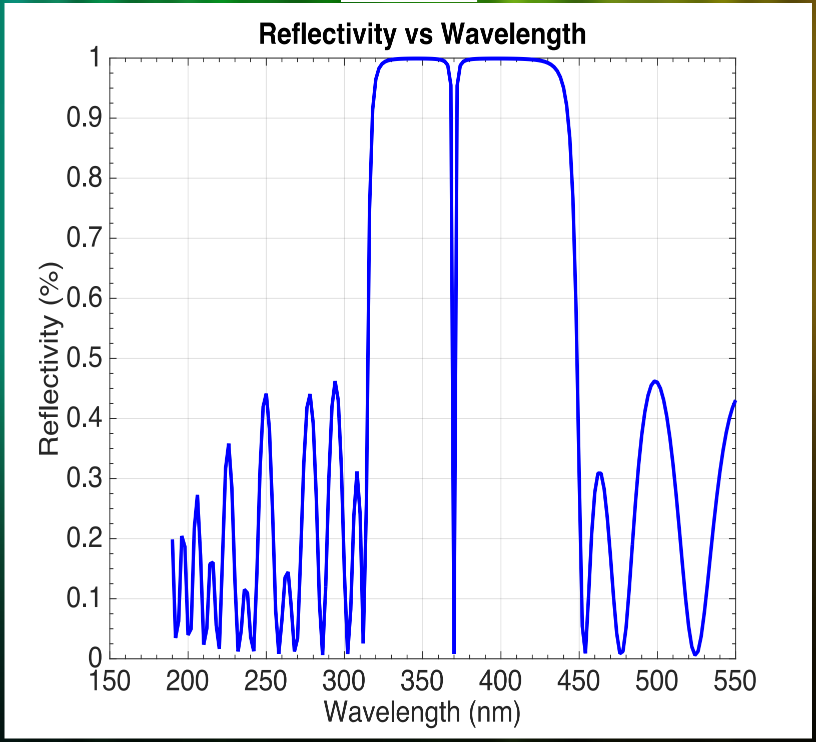
Changing the substrate index affects maximum transmission.

Before



High Index

After

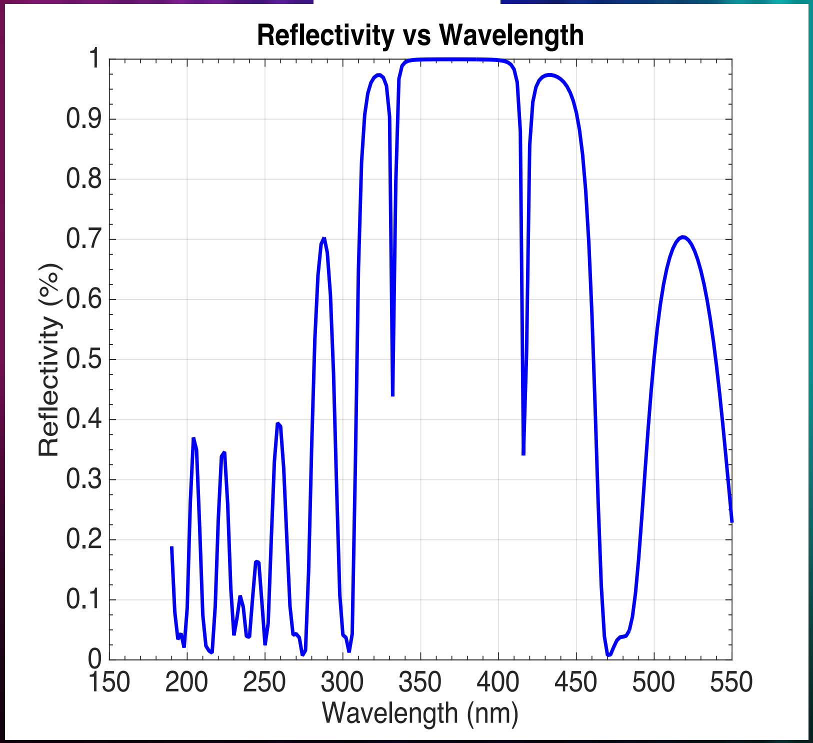


Low Index

Results

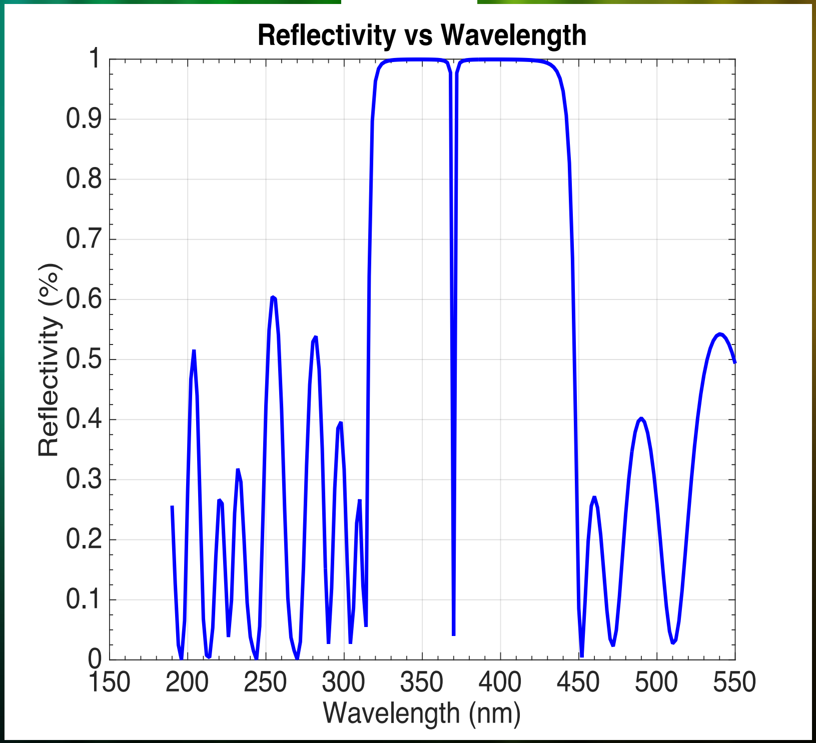
Changing the cavity index affects reflection patterns.

Before



Far from Integer

After

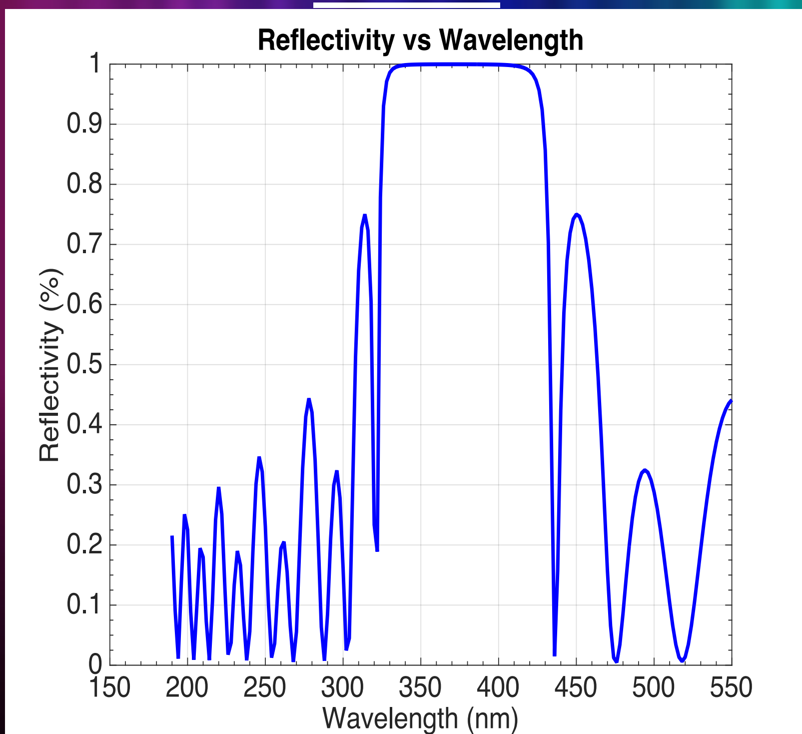


Close to Integer

Results

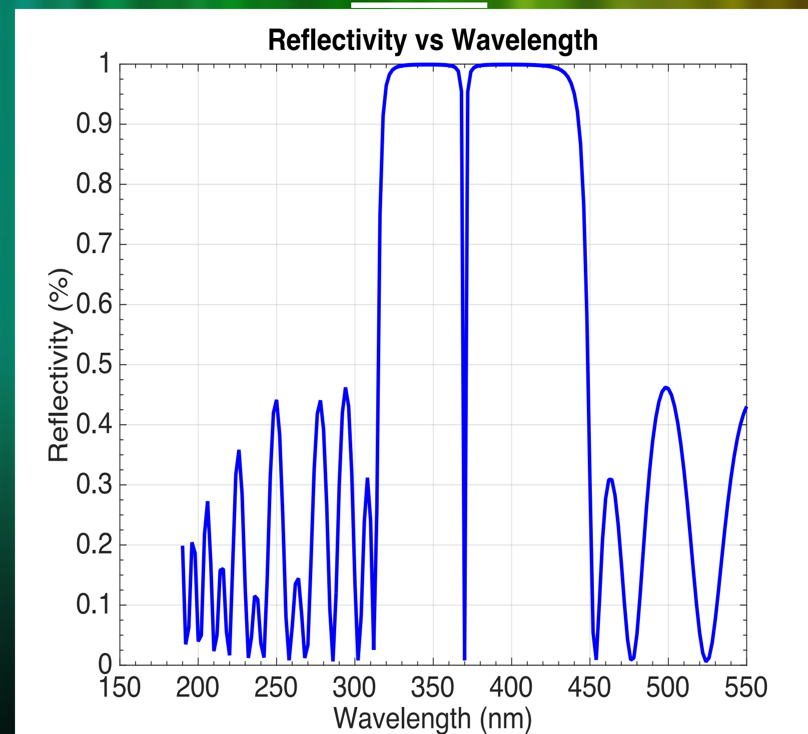
Changing the length of the microcavity affects transmission at the Bragg wavelength.

Before



1/8 Bragg wavelength

After



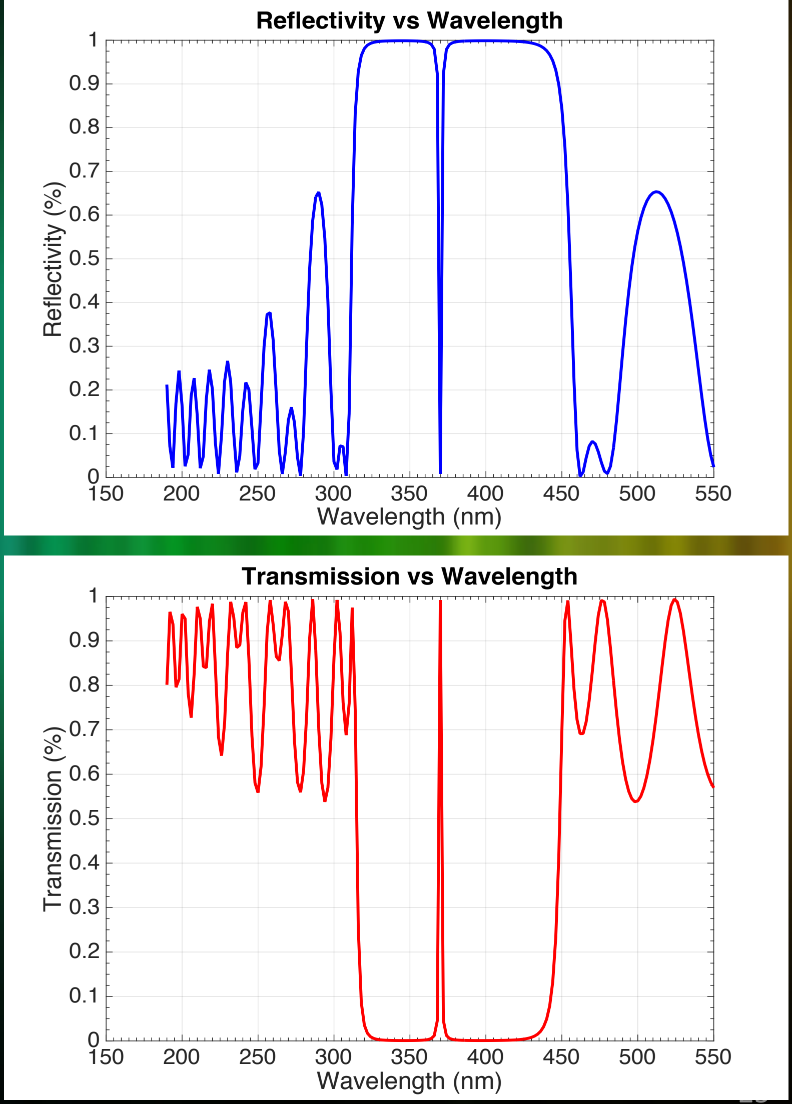
1/2 Bragg Wavelength

Conclusion

Final

For Maximum Transmission:

1. Equal DBR stacks above and below cavity.
2. Substrate refractive index close to 1.0 (vacuum).
3. Cavity refractive index close to integer.
4. Cavity length of $1/2$ or $1/4$ the Bragg wavelength.



ORGANIC LIGHT EMITTING DIODE LIGHTING

- Introduction
  - What is an Organic Light-Emitting Diode?
  - OLEDs Compared to Other Light Sources
  - History and Applications of Organic Light-Emitting Diodes
  - How Does it Work?
- Method
- Results and Conclusion
- Why is it the Next Generation of Technology?

Organic Light-Emitting Diodes

ADVANTAGES

- Energy efficient
- Environmentally friendly
- Does not emit heat or UV rays
- Closest light source to natural light
- Thinner and lighter than other light sources
- Cost decrease predicted to occur in the next 5 years
- Can be produced as large sheets
- Truer blacks and better contrast on displays

DISADVANTAGES

- Efficiency is still low compared to LED efficiency
- Blue OLED lifetime is much shorter than the red and green
- The cost to manufacture is currently expensive
- Sensitive to water and UV rays

Potential OLED Applications

http://www.superimaging.com/img/hud1.jpg

http://www.ledsmagazine.com/content/dam/leds/migrated/objects/news/6/7/10/GECIA_Clothes.jpg

http://www.demilked.com/magazine/wp-content/uploads/2014/10/windowless-passenger-plane-oled-touchscreen-walls-cpi-6.jpg

Sources

1. Heavens, O. S. Optical Properties of Thin Solid Films. London: Butterworths Scientific Publications, 1955. Print.
2. Geffroy, Bernard, Philippe Le Roy, and Christophe Prat. "Organic Light-emitting Diode (OLED) Technology: Materials, Devices and Display Technologies." *Polym. Int. Polymer International* 55.6 (2006): 572-82. Print.
3. Kalyani, N. Thejo, and S.j. Dhoble. "Organic Light Emitting Diodes: Energy Saving Lighting Technology—A Review." Renewable and Sustainable Energy Reviews 16 (2012): 2696-723. Print
4. "OLED Technology: Introduction and Basics." *OLED Technology: Introduction and Basics*. Web. 6 July 2015.
5. Howard, W. E., and O. F. Prache. "Microdisplays Based upon Organic Light-emitting Diodes." IBM Journal of Research and Development IBM J. Res. & Dev. (2001): 115-27. Print.
6. Burroughes, J.H. "Light-emitting Diodes Based on Conjugated Polymers." Nature 347 (1990): 352. Print
7. Antoniadis, Homer, Ph.D. "Overview of OLED Display Technology." Osram Optical Semiconductors. http://www.ewh.ieee.org/soc/cpmt/presentations/cpmt0401a.pdf
8. "DuPont shows new AMOLED materials and OLED displays" OLED-Info.com.
9. Howard, Webster E. "Better Displays with Organic Films." Sci Am Scientific American (2004): 76-81. Print.
10. "Kodak Unveils World's First Digital Camera with OLED Display" Eastman Kodak. 3/2/2003.
11. Michael J. Felton (2001) "Thinner lighter better brighter, Today's Chemist at Work."; 10 (11): 30-34
12. Williams, Martyn. "PC World - Sony Readies OLED TV".4/12/2007.
13. Reisinger, Don. "LG Display Shows off Press-on 'wallpaper' TV under 1mm Thick - CNET." CNET. 19 May 2015. Web. 6 July 2015.
14. Schubert, E. Fred. "Light Emitting Diodes and Solid-State Lighting." Light Emitting Diodes

Acknowledgements

National Aeronautics and Space Administration (NASA)

NASA Goddard Space Flight Center, Office of Education (GSFC)

NASA Goddard Institute for Space Studies (GISS)

NASA New York City Research Initiative (NYCRI)

LaGuardia Community College (LAGCC)

Samhita Roy, Student, WWP South

Dr. John R.E. Toland, Physics Professor, LAGCC

ORGANIC LIGHT-EMITTING DIODES

LIGHTING TOWARD A SUSTAINABLE ENVIRONMENT

Colleen Cleary (Undergraduate)

Leo Panish (HS Student)

Angelo Angeles (HS Teacher)

Dr. Reginald Eze (Mentor)

Dr. Yasser Hassebo (Mentor)

FAQ

ORGANIC LIGHT-EMITTING DIODES

LIGHTING TOWARD A SUSTAINABLE ENVIRONMENT

Excitons

Circuit Basics

Applying the Layers

Microcavity

Semiconductors

Algorithm Steps

DBR

P-N Junction

Natural Light

OLED Materials

Layers of an OLED

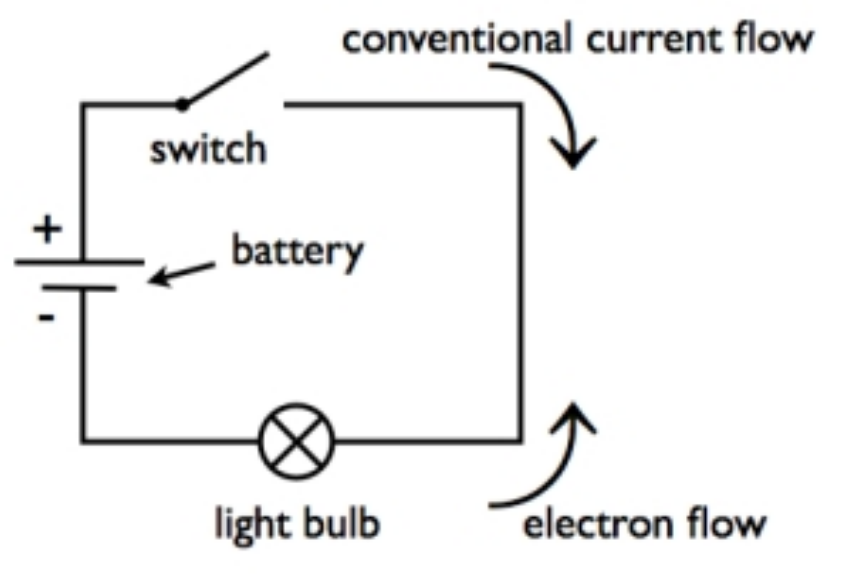
Black Levels/Contrast

Equations

Home

Circuit Basics

- Potential difference (voltage) creates a push
- Current flows through circuit
- Resistance restricts flow
- Direct current and alternating current

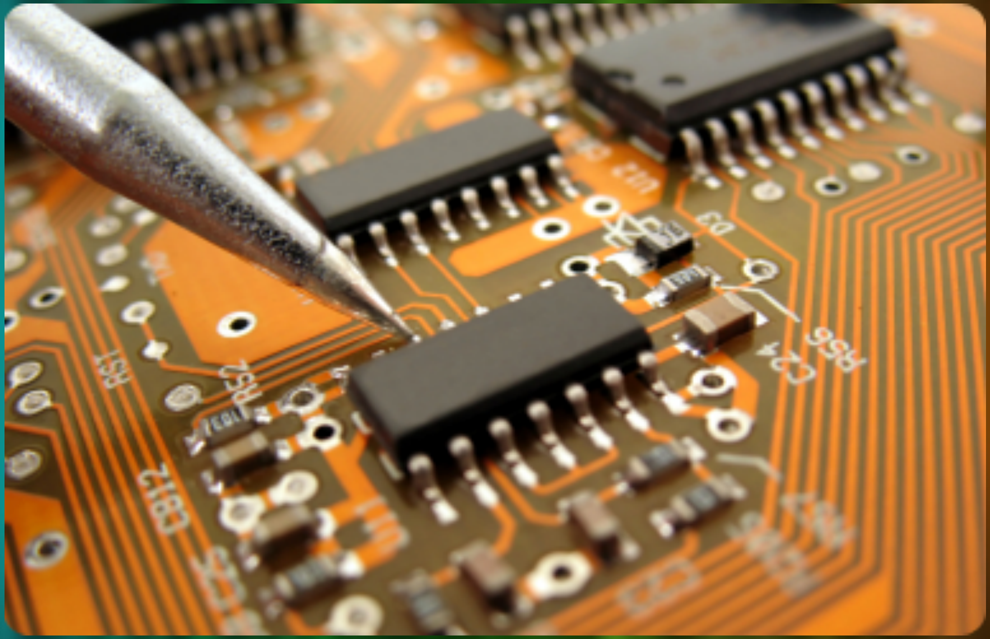


http://www.rkm.com.au/ANIMATIONS/animation-graphics/circuit-diagram.jpg

Main Menu

Semiconductors

- Conductivity increases with temperature.
- Allows for greater control of current.
- Used in transistors, diodes, microprocessors.
- Usually Silicon and Germanium



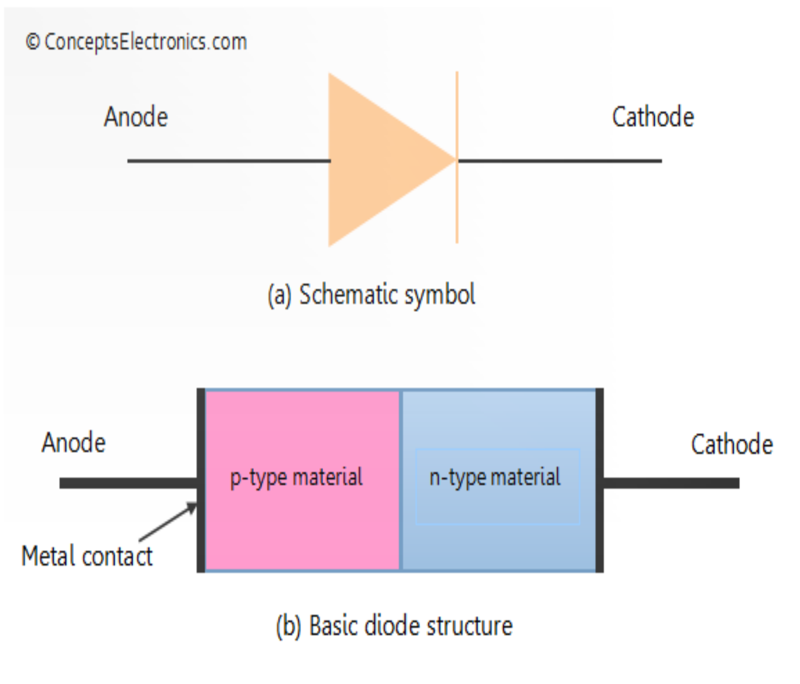
http://lubricationtechnology.com/uploads/images/pageimages/semiconductor.png

Main Menu

P-N Junction

P Material

- Semiconductor doped with an impurity that has fewer valence electrons
- The missing electron leaves a positively-charged "hole"

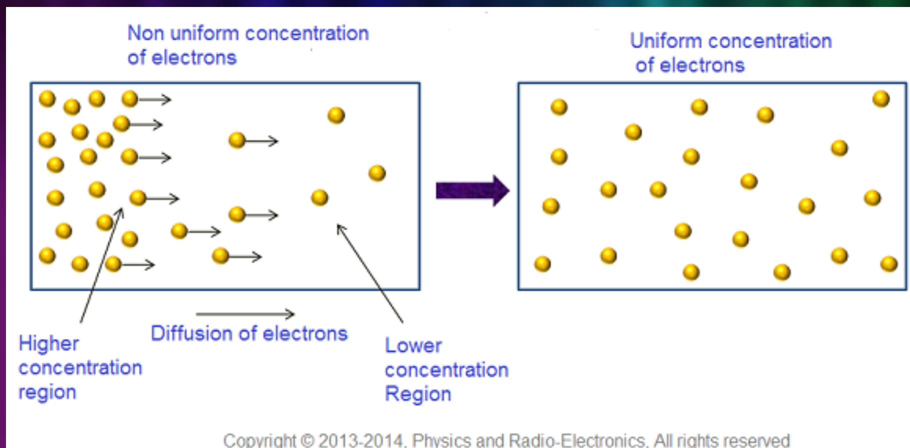


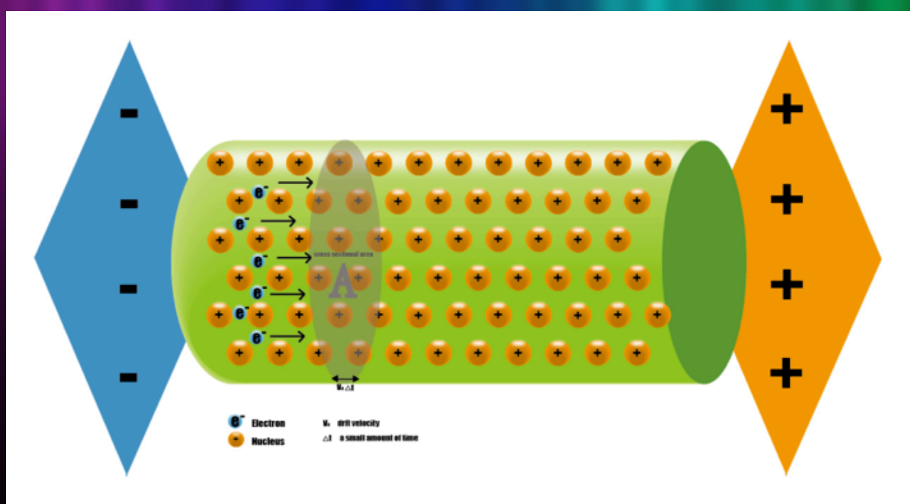
N Material

- Semiconductor doped with an impurity that has extra valence electrons
- Extra electrons can move freely and conduct electricity

Main Menu

P-N Junction





Diffusion

Random movement of electrons to fill an entire space (no current)

Drift

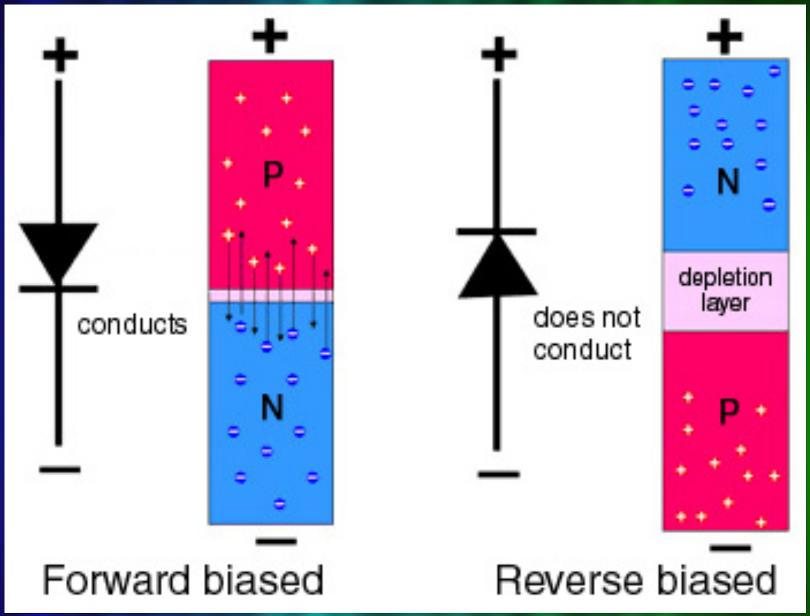
Movement of electrons due to an electric potential (current)

[Main Menu]

P-N Junction

Forward Bias

- **works with drift to decrease the depletion zone**
- **negative current pushes electrons across**
- **current created**



circuitstoday.com/pn-junction-diode-characteristics

Reverse Bias

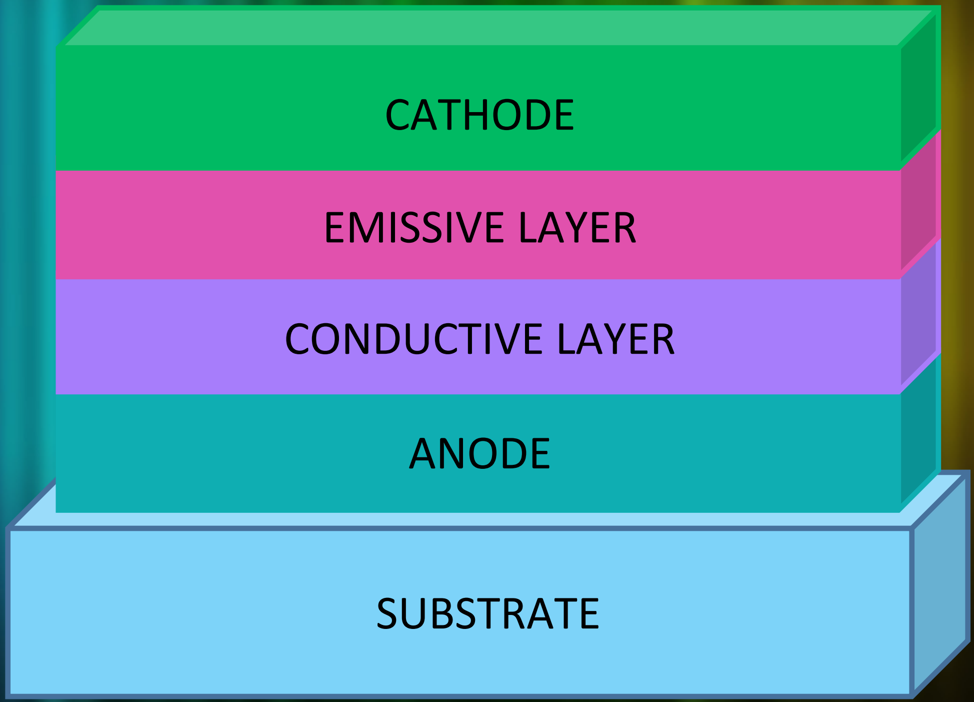
- **works against drift and with diffusion**
- **increases the depletion zone**
- **negligible current**

Current can only flow in one direction.

Main Menu

Basic OLED Structure

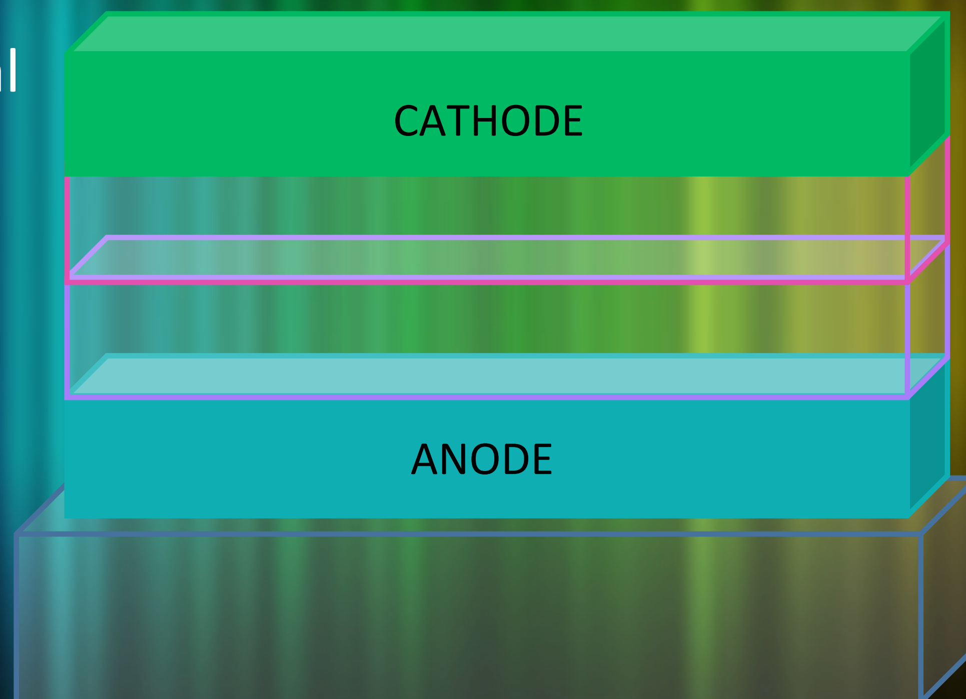
- Invented by Kodak in 1987
- Only two layers between cathode and anode.



Main Menu

Cathode and Anode

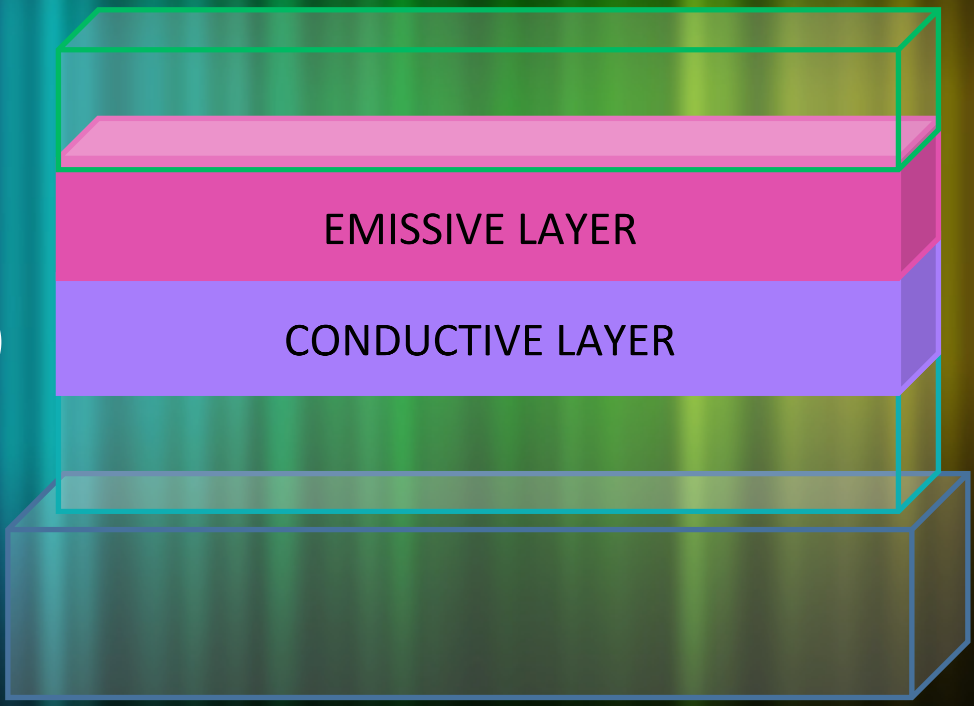
- Cathode: Electrode that receives electrons when connected to a power source
- Typically a reflective metal
- Anode: Electrode that loses electrons (or "receives holes")
- Often transparent and made of indium tin oxide (ITO)



Main Menu

Emissive and Conductive Layers

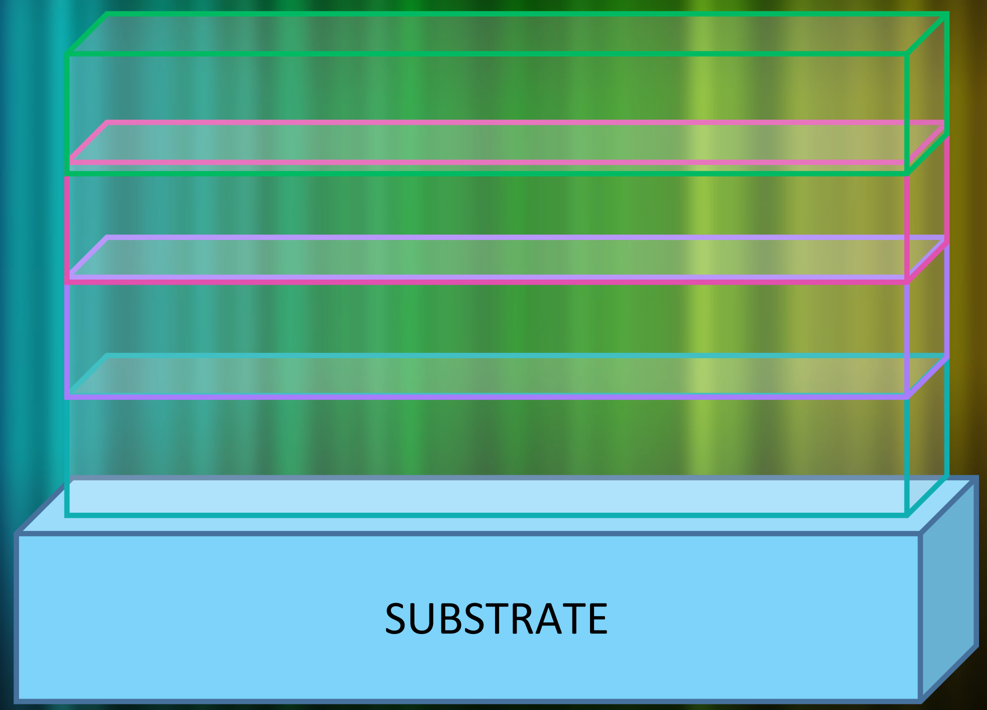
- Thin organic material between cathode and anode
- Combined thickness: 100-150 nanometers
- Electrons are transported to the emissive layer (ETL)
- “Holes” travel through conductive layer (HTL)
- Electrons and holes recombine in the ETL
- Energy is released in the form of light



Main Menu

Substrate Layer

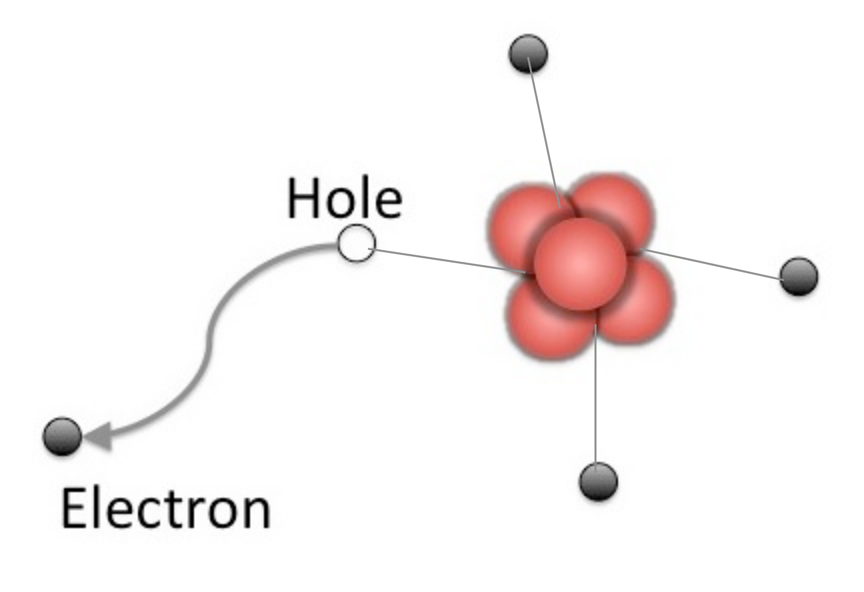
- A protective, transparent layer
- Light passes through the clear substrate



Main Menu

Recombination and Excitons

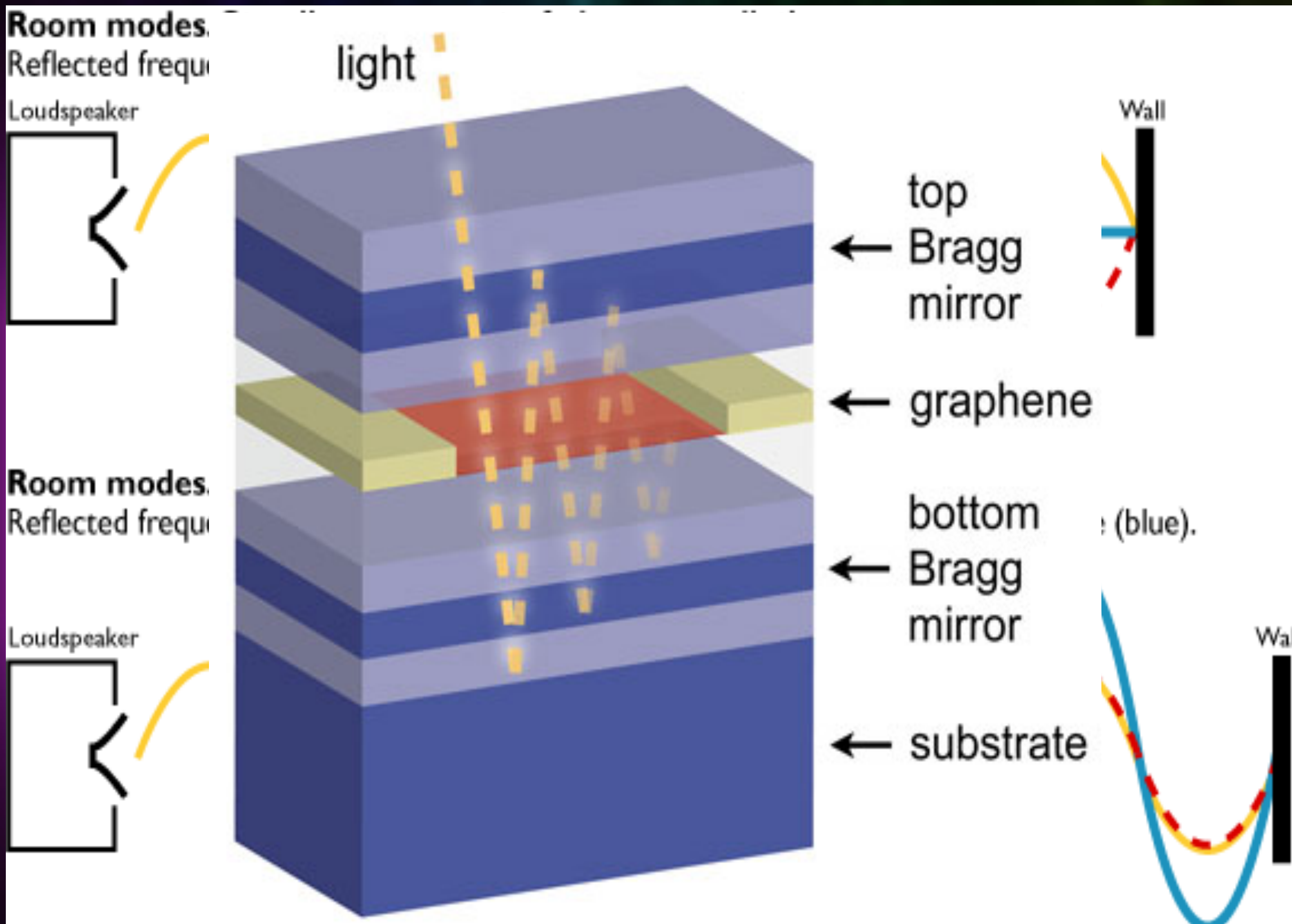
- Electrons and holes recombine.
- The recombination forms exciton and releases light.
- Exciton (electron-hole pair) is electrically neutral.



https://www.solarquotes.com.au/img/solar-pv-effect3.jpg

Main Menu

Microcavity

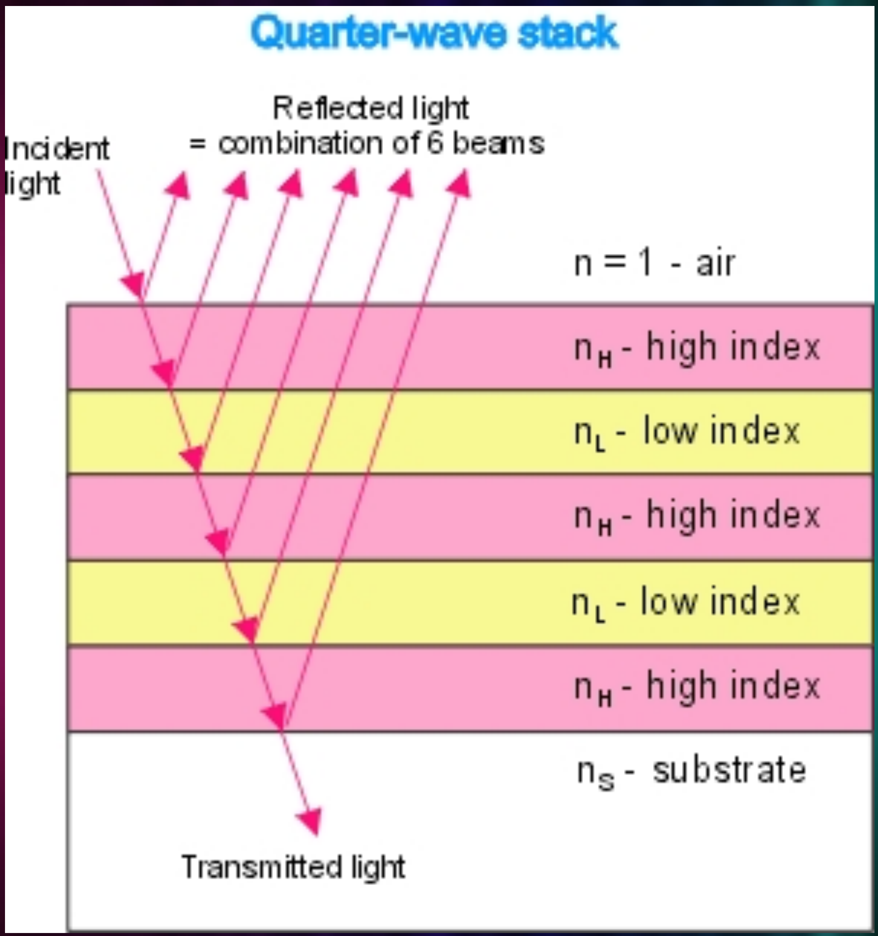


http://www.nanowerk.com/spotlight/id25220.jpg

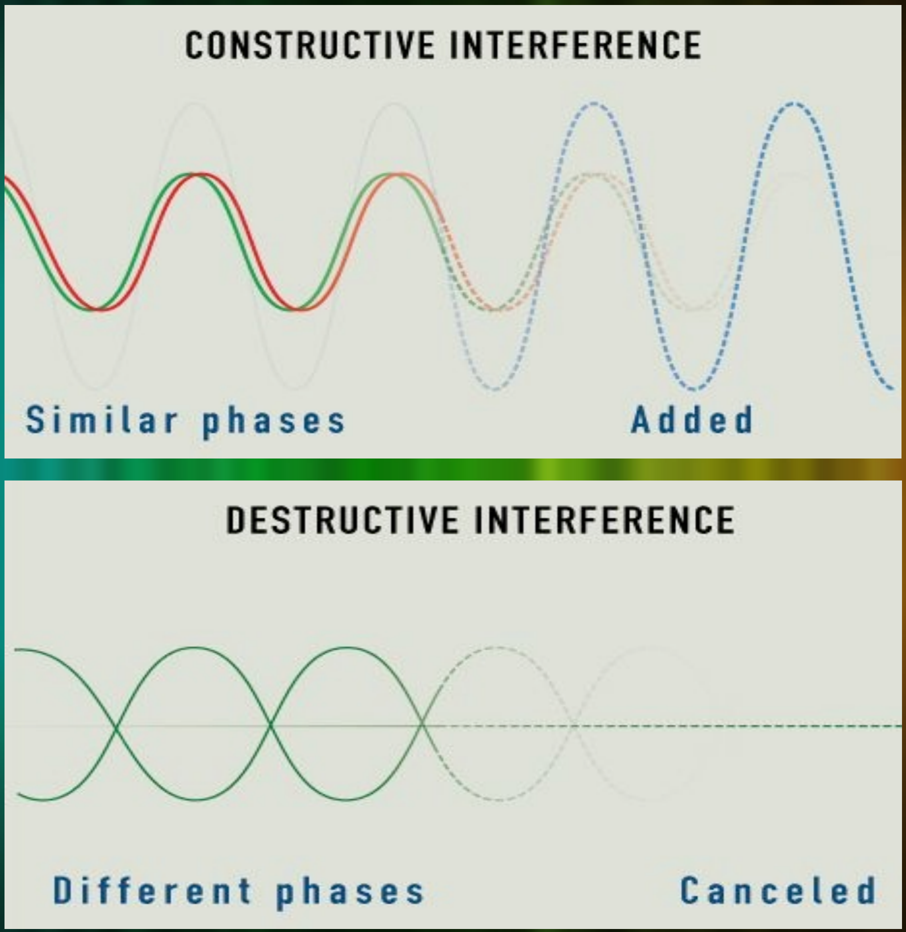
http://www.planetoftunes.com/sound-audio-theory/so_media/standing_waves.gif

Main Menu

Distributed Bragg Reflector



http://www.batop.de/information/pictures/quarter-wave_stack.jpg



http://www.webexhibits.org/causesofcolor/images/content/11z.jpg

Main Menu

OLED Materials

Cathode

- Aluminium
- Silver
- Magnesium
- Indium
- Lithium-fluoride

Electron Transport Layer (ETL)

- Tris-(8-hydroxyquinoline) Aluminum

Emissive Layer

- Tris-(8-hydroxyquinoline) Aluminum
- Coumarin
- Dichloromethane

Hole Transport Layer (HTL)

- Copper phthalocyanine
- Naptha phenyl benzidene

Anode

- Indium-tin oxide
- Zinc oxide

Main Menu

Mathematical Concepts

Characteristic Matrix

- Necessary in order to calculate reflection and transmission.
- There is a characteristic matrix for:

  Upper DBR, M_{DBR1}

  Microcavity, M_{Cavity}

  Lower DBR, M_{DBR2}

- The total characteristic matrix can be found using:

$$M_{Total} = M_{DBR1} * M_{Cavity} * M_{DBR2}$$

Main Menu

Mathematical Concepts

Reflection and Transmission Equations

- M_{Total}, a 2x2 matrix, contains real and imaginary parts.
- The top and bottom two elements of the matrix form two complex numbers, denoted as B and C, respectively.

It is possible to calculate the reflection and transmission, given by:

$$R=\left(\frac{y_0 * B-C}{y_0 * B+C}\right)\left(\frac{y_0 * B-C}{y_0 * B+C}\right)$$

$$T=\frac{4 y_0 \, Re(y_{sub})}{(y_0 * B+C)(y_0 * B+C)}$$

Main Menu

Applying the Organic Layers

- Vacuum Thermal Evaporation (VTE):
  - Organic molecules are evaporated and condensed.
  - Kodak's original process.
  - Expensive and inefficient.

- Organic Vapor Phase Deposition (OVPD)
  - Carrier gas transports evaporated organic molecules
  - More efficient and less expensive.

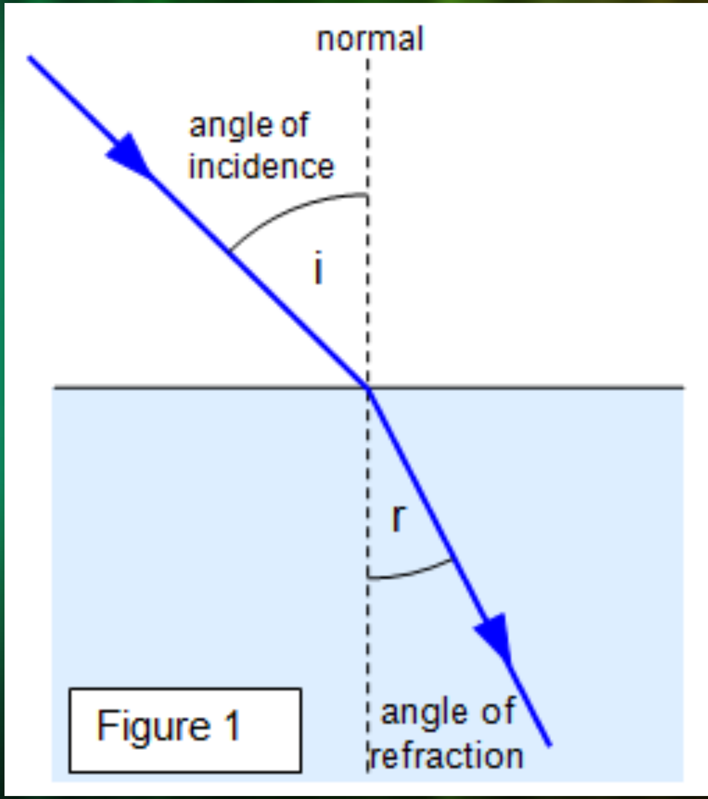
- Inkjet Printing
  - Materials sprayed directly to substrate.
  - Most efficient and least expensive application technique.

Main Menu

Defining Parameters

Steps 1-2

- User enters properties of the layers:
  - Number of layers
  - Angle of incidence
  - Index of refraction
  - Wavelength
- Convert from degrees to radians



http://www.schoolphysics.co.uk/age16-19/Optics/Refraction/text/Refraction_/images/1.png

Main Menu

Calculating Material Properties

Steps 3-5

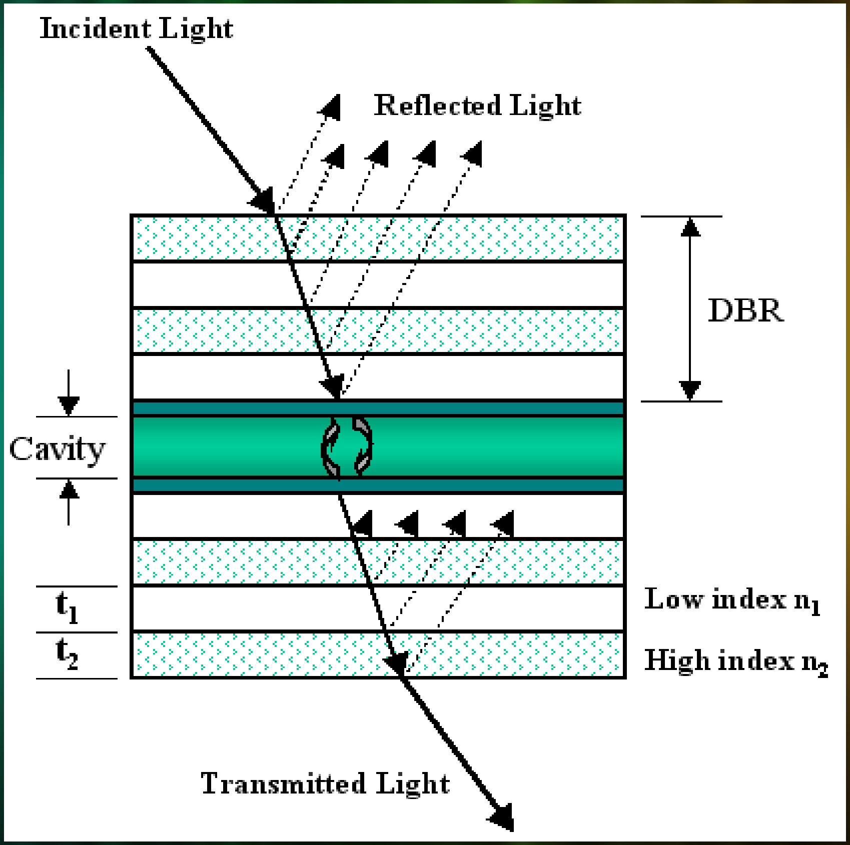
- Test all possible initial incident angles (-90° to 90°)

- Find values:

  Incident angle of m^{th} layer, θ_m

  Thickness of each layer, d

  Optical admittance, y



Showing how the light behaves in the DBR structure

Main Menu

Changing Wavelengths

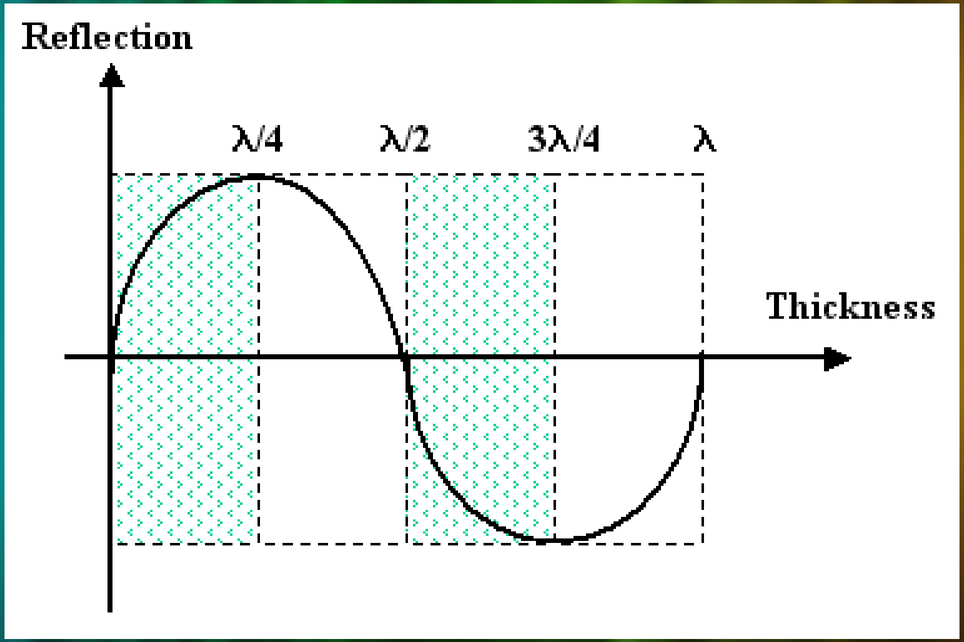
Steps 6-7

- Test visible spectrum with each initial incidence angle
- Determines values for:

  Phase change, $\delta\downarrow m$

  Characteristic matrix, $M\downarrow m$

  Total characteristic matrix, $M\downarrow T$



Showing the maximum and minimum reflection in the DBR layers.

Main Menu

Results

Steps 8-9

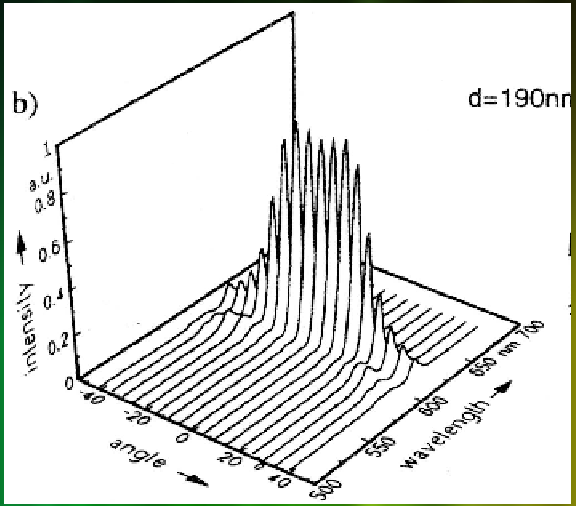
- Receive output when all possibilities have been checked. Includes:

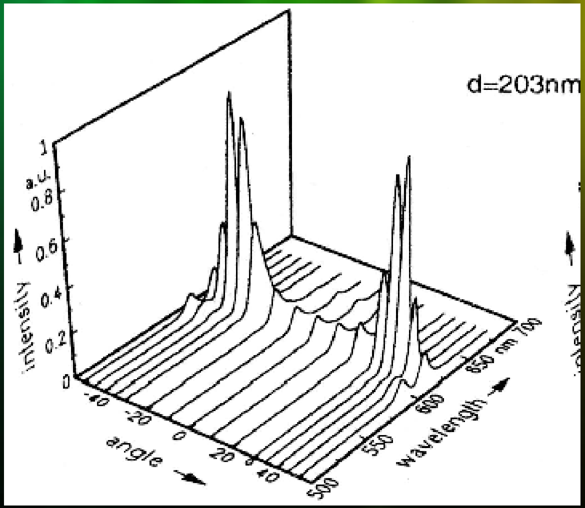
  Reflectance, R

  Transmittance, T

  Phase angle, Ψ, between R and T

- Produce graphs from results

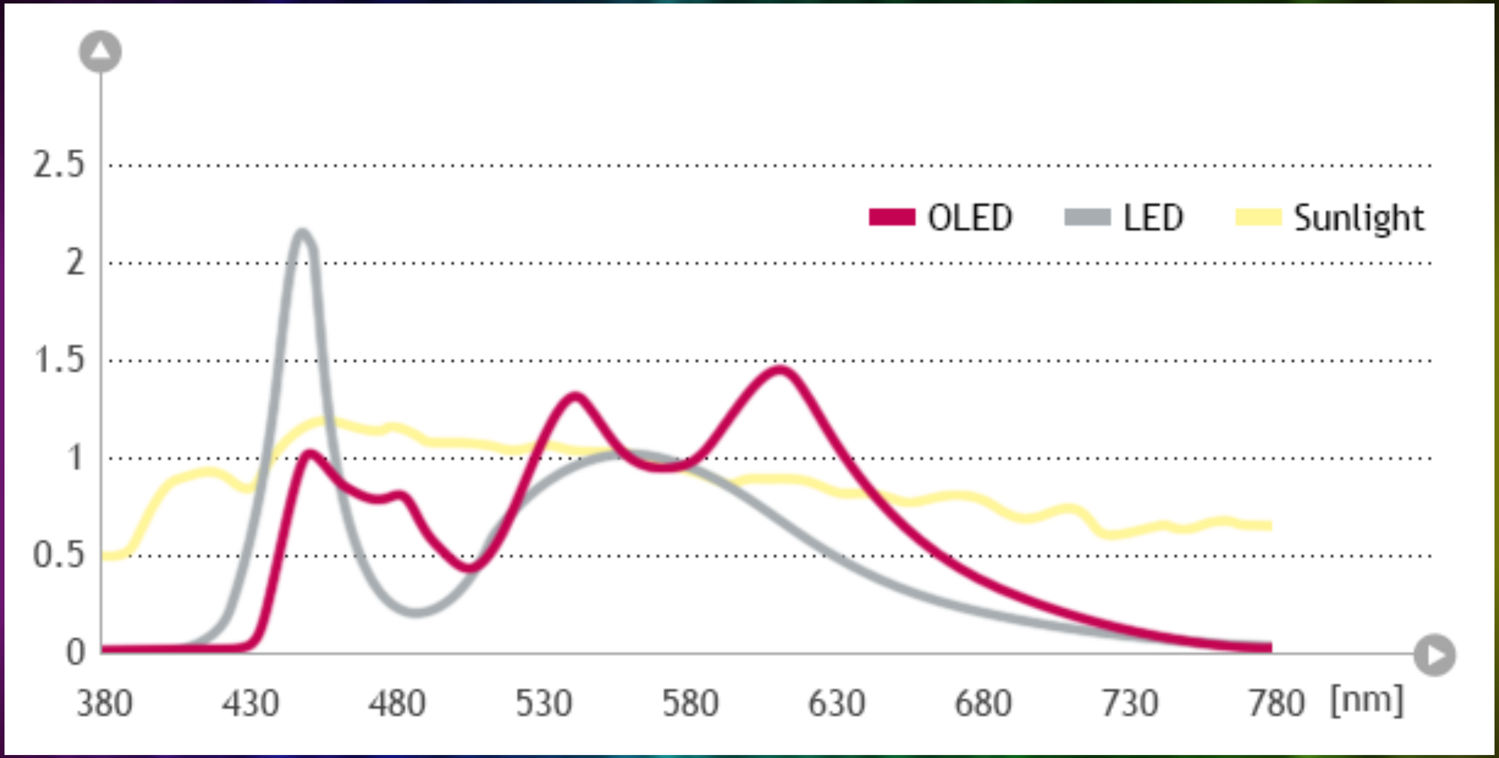




Siegfried Dirr, Stefan Wiese, Hans-Hermann Johannes, and Wolfgang Kowalsky, “Organic Electro- and Photoluminescent Microcavity Devices”, Advance Material, 10(2), 167-171, (1998).

Main Menu

Spectral Power Distribution



http://www.lgoledlight.com/

Main Menu

Black Levels and Contrast

http://www.consumerreports.org/cro/news/2014/10/lg-s-oled-tv-isn-t-the-best-tv-we-ve-ever-tested/index.htm

Black displayed on an OLED TV (left) and LCD TV (right).

Main Menu